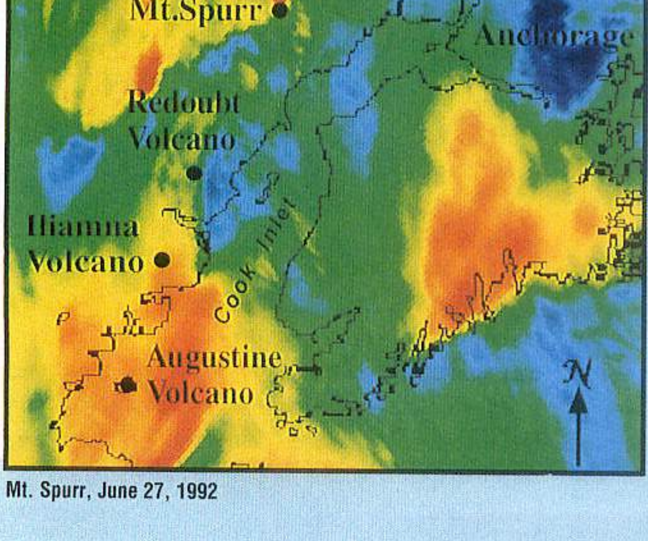
VOLCANIC HAZARDS AND AVIATION SAFETY:

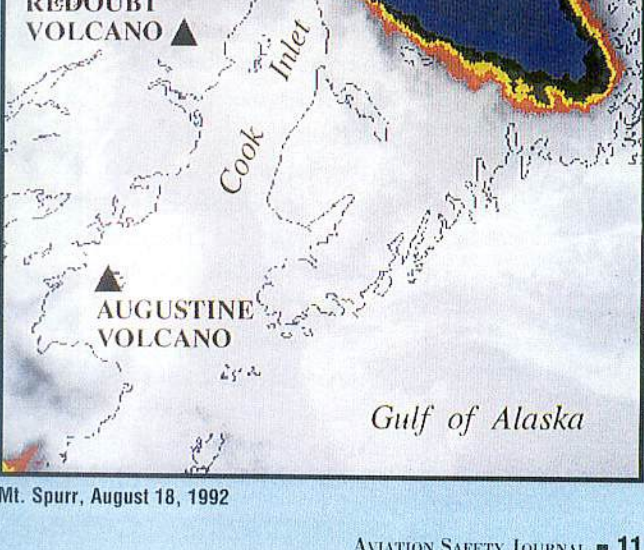
DEVELOPING TECHNIQUES IN ALASKA

This article by the Alaska Volcano Observatory was written in response to the FAA Aviation Safety Journal's (Vol. 2, No. 3). article "Volcanic Hazards and Aviation Safety: Lessons of the Past Decade," by Thomas J. Casadevall.

Thermal infrared images of eruption clouds. On left photo, red tones represent very cold temperatures on the image. The eruption cloud is hot when first emitted but cools very rapidly as it ascends. On right photo, blue tones represent very cold temperatures (approximately -60°C).



Mt. Spurr, June 27, 1992



Mt. Spurr, August 18, 1992

Alaska Volcano Observatory

Since the two nearly fatal incidents involving Boeing 747 jet aircraft encounters with volcanic ash from Galanggung Volcano in Indonesia in 1982, programs that could help prevent these incidents have been slow to be developed. Recognizing the volcanic hazard to aviation safety in Alaska, the Geophysical Institute of the University of Alaska Fairbanks, the U.S. Geological Survey, and the Division of Geological and Geophysical Surveys of the State of Alaska jointly established the Alaska Volcano Observatory (AVO) in 1987. *(See box for more information about AVO.)*

The AVO concentrates its efforts on the monitoring of active volcanoes in the Cook Inlet area and issues alerts when eruptions appear to be imminent. The AVO was operational and able to respond at the time of the eruption of Redoubt Volcano on December 14, 1989 (Brantley, 1990). The volcano is located about 100 miles southwest of Anchorage. A warning was issued about midnight on December 13, about 10 hours before the eruption, due to very active seismicity recorded by several seismometers on the volcano. The warning was sent to the FAA office in Anchorage, the Elmendorf AFB, the Anchorage Municipality, the State Department of Emergency Services, and others.

Figure 1: (Above) An AVHRR satellite image showing an eruption cloud from Redoubt Volcano, January 8, 1990 at 1928 UT, 20 minutes after an eruption. The circular eruption cloud (red and black) is slightly east of Redoubt Volcano due to eastward blowing winds. This volcano is located 100 miles SW of Anchorage.

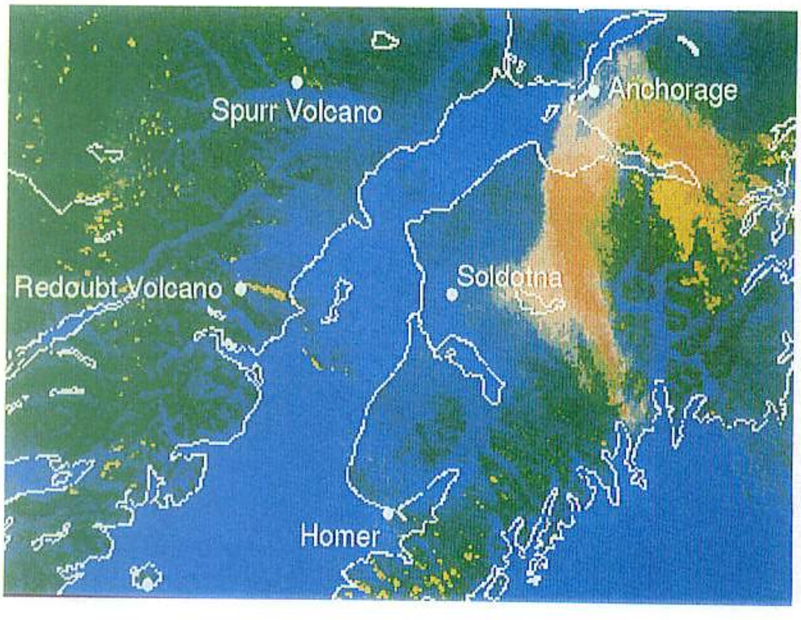


Figure 2: (Right) An AVHRR satellite image showing the position of the same eruption cloud in Figure 1 but 4 hours later. The eruption cloud has been carried 100 miles east of the volcano, but the cloud is now elongated stretching from Alaska's southern coast to north of Anchorage. An hour earlier ash from the eruption cloud rained on Soldotna "turning day to night."

Close encounter

In spite of such warnings, a Boeing 747 jet aircraft experienced a near-crash incident from an encounter with a cloud of volcanic ash from Redoubt Volcano on December 15, 1989. Scientists at the Geophysical Institute and the AVO realized that in addition to the prediction of eruptions, aviation safety cannot be improved without also being able to predict the movement of volcanic ash after an eruption. AVO also found that the prediction of the movement of airborne volcanic ash is generally outside the main mission of all concerned federal agencies and requires close cooperation of at least three agencies, the Federal Aviation Administration (FAA), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS).

Establishing a simulation model

After learning of the nearly fatal incident, a study was initiated that would simulate the movement of airborne volcanic ash in the immediate vicinity of a volcano as well as at greater distances at specified time intervals of 0.5 hours, 1 hour, 2 hours, 3 hours, and so on. It was decided to employ a general pollutant-tracking Lagrangian model. In this model, thousands of plume particles (test particles) are "released" in the air column over a specified volcano. Trajectories of individual particles are then computed, using upper-air wind data. The particles fall due to gravity, however, down-wind movement and spreading also takes place. A three-dimensional, statistical model based on random movement of particles is used to simulate this dispersion. The accuracy of upper-air wind data is essential in the model, and it was decided, as a test, to use *Unidata* for wind flow information. *Unidata* is a national program in atmospheric sciences that makes it possible to acquire, via satellite down-link, near real-time meteorological data from around the world.

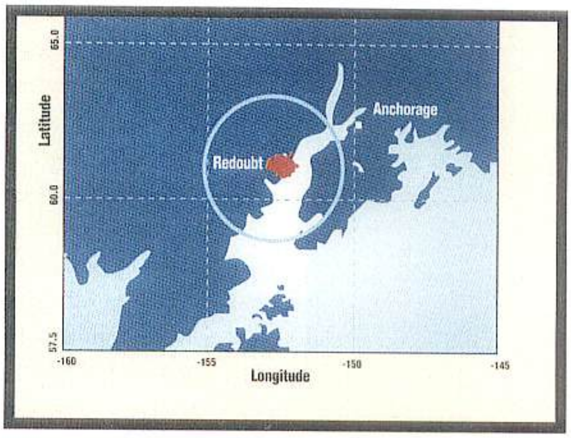


Figure 3: (Left) A computer model of the January 8, 1990 eruption-cloud shown in Figure 1. It takes only a few minutes to run this simulation.

The simulation shows the position and extent of the ash-cloud and provides information about ash cloud density by counting the number of ash particles per unit volume of the air. The ash cloud density inferred in this manner is assumed to be proportional to the actual mixing ratio of volcanic ash through a multiplier constant. The typical value of this multiplier constant can be estimated from the ground sampling of the ash deposit and compared with the amount of gravitational fallout from the ash-cloud in the model.

Funds needed for the task were provided by contributions from the National Science Foundation, the Alaska Science & Technology Foundation, and several airline and other associated companies. The first tests and demonstration of the simulation were conducted in the spring and summer of 1991 using data from previous eruptions from Redoubt Volcano in 1989-1990 and hypothetical eruptions (Tanaka, 1991).

Validating test results

During early tests of the model (winter of 1990-1991), the question of verifying the accuracy of the results arose. It was suggested that satellite images could accomplish this task. Advanced Very High Resolution Radiometer (AVHRR) satellite images of the January 8 eruption of Redoubt Volcano were processed to coincide with a plume tracking simulation. The corresponding images (Figures 1 and 2) were analyzed to show the position of the eruption cloud as it moved across the state and compared them to the tracking simulation for validation (Figures 3 and 4). The results, obtained 1 year following the actual eruption, were startlingly accurate and show the potential for a model that simulate atmospheric conditions near an active volcano.

Validating the simulation by satellite images is essential. After comparing the predicted movement of the plume to the position shown on a satellite image and adjusting some parameters, the accuracy of the simulation can be increased significantly. During the validation process, AVO noted that one of the important inputs in the simulation is the initial height of the top of the plume.

Unfortunately, heights cannot always be determined by field observations. The height of the plume, however, can be estimated by correlating the temperature of the upper plume surface to the thermal profile of the atmosphere and to wind velocity and direction. A volcanic plume stops ascending when its temperature becomes that of the surrounding upper air. The thermal infrared AVHRR data detects the temperature of the top of the plume, for example, -50°C. Meteorological balloons launched twice daily from the Anchorage Airport measure the air temperature as the balloon ascends, for example, -50°C at 40,000 feet. By comparing the temperature of the plume derived from the satellite images to the atmospheric temperature, the altitude of the plume can be estimated.

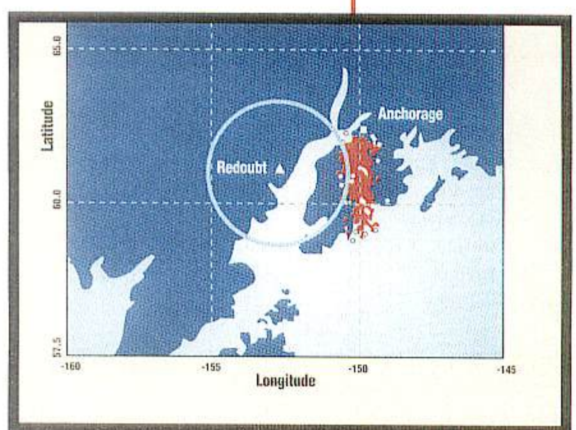


Figure 4: (Above) The same computer model in Figure 3 is allowed to run longer to show the position of the eruption-cloud recorded on the satellite image in Figure 2, approximately 4 hours after the eruption. This model is designed to show the position of that portion of the eruption cloud that contains ash while the satellite image records ash and gas.

When using this technique, the portions of the plume that are very cold should be avoided (Dean, et. al. in press) because of possible errors in height estimates (Woods and Self, 1992). Since duplicate temperatures can occur at multiple heights, wind velocity and direction at the possible altitudes are compared to the position of the plume shown on the satellite image to further refine the estimate. Pilot reports that include an estimate of the plume height are also used when available.

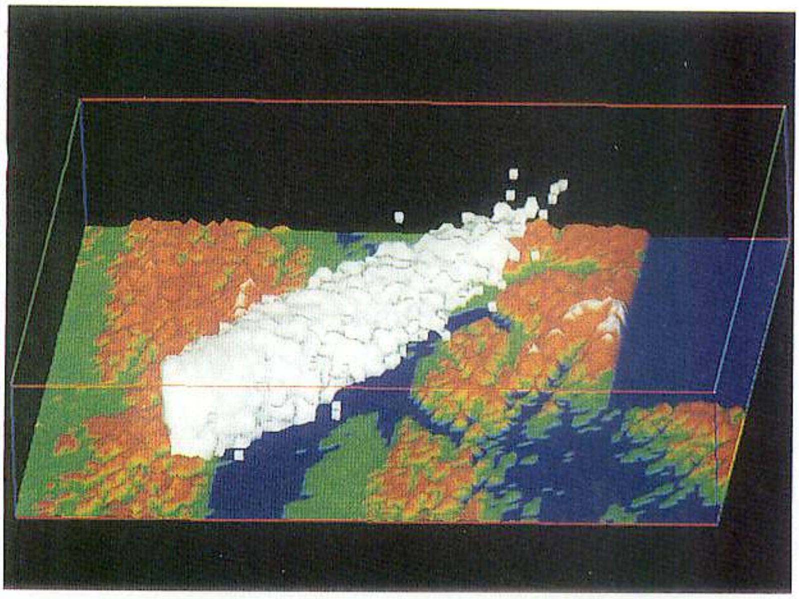


Figure 5: A computer model of a perspective view of the Cook Inlet region showing an eruption-cloud. This rendering is designed to simulate the view from the cockpit of an aircraft as it approaches the Cook Inlet region. The plume was modeled from the December 16, 1989 eruption of Redoubt Volcano.

An ongoing process

Since the eruption of Redoubt Volcano, AVO has been improving its simulation model. In particular, AVO is trying to make the results more easily understandable by using a three-dimensional perspective rendering. The perspective rendering (Figure 5) is similar to the view from the cockpit of an aircraft as it approaches the Cook Inlet region with a volcanic plume, modeled from the December 16 eruption of Mt. Redoubt, near the center of the image. This example was chosen, because it is located near one of the more heavily traveled air corridors in the northern Pacific. The presence of similar simulations in the control towers of airports would improve the capabilities of the traffic controller to guide aircraft around the plume.

The point of this short article is to demonstrate that a high resolution computer simulation of the movement of airborne volcanic ash in the vicinity of active volcanoes will significantly improve aviation safety. At this time satellite images are processed as soon as possible after the start of an eruption, and the results are provided to the AVO to be incorporated into the overall eruption response. Operational use of the meteorological data and computer modeling of ash clouds are still under development and refinement by scientists at the Geophysical Institute and the AVO. While in the development stage, results may be provided to interested groups for comments and/or during eruptions emergencies. While a supercomputer will be used during the research and development stage to increase computational capabilities of models and visualizations, the AVO intends to have the model and renderings run on affordable workstations. ✈

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Alaska Volcano Observatory

The Alaska Volcano Observatory (AVO) is one of three observatories operated under the U.S. Geological Survey's (USGS) Volcano Hazard Program. The AVO is responsible for monitoring and alerting businesses and communities of eruptions of the most active explosive volcanoes in the Nation: Those of the Aleutian Arc. AVO practices the uncertain science of predicting eruptions in the challenging environment of towering, ice-clad, steaming mountains. The main tools for monitoring are remote networks of seismic stations. These stations are supplemented with satellite imagery, lightning detection, remote video cameras, and periodic gas-sampling flights, and they are enlightened by geologic insights into past eruptions.

The primary hazard is to the tens of thousands of national and international flights that pass over this Aleutian line of smoking guns every year. Additionally, there is the continued potential for damage to transportation and energy facilities, and for interruption of everyday life in Alaskan communities.

AVO is a cooperative effort of

Kenneson Gene Dean is a Research Assistant Professor, Geophysical Institute, University of Alaska Fairbanks. He is responsible for the analysis of volcanic eruption-clouds recorded on satellite images during an eruption and provides this information to the Alaska Volcano Observatory. He is also involved in basic research on the detection of eruption clouds on satellite images.

Dr. Syun-Ichi Akasofu is the Director of the Geophysical Institute, University of Alaska Fairbanks. Dr. Akasofu is a professor of physics and is well known for his research on the Aurora Borealis. He was instrumental in the creation of the Alaska Volcano Observatory and facilitates the merging of Dr. Tanaka's modeling research with AVO activities.

Dr. Hiroshi Tanaka is an assistant professor of atmospheric sciences, Institute of Geosciences, University of Tsukuba and an adjunct professor of physics at the University of Alaska Fairbanks. Professor Tanaka developed the plume tracking model discussed in this paper. He teaches courses on meteorology and climatology and continues to perform research refining his model of volcanic eruption clouds.

References

Brantley, S.R. (ed.), The Eruption of Redoubt Volcano, Alaska, December 14, 1989 - August 31, 1990, U.S. Geological Survey Circular 1061, 1990.

Dean, K. G., S. A. Bowling and G. Shaw, Satellite Analyses of Movement and Characteristics of the Redoubt Volcano Plume, 8 January 1990. Jour. of Volc. and Geothermal Res., In press.

Tanaka, H. L., Development of a Prediction Scheme for the Volcanic Ash Fall from Redoubt Volcano: First International Symposium on Volcanic Ash and Aviation Safety, Seattle, Washington, July 8-12 1991, U. S. Geological Survey Circular 1065, pp. 58.

Woods, A. W. and Self, S., 1992. Thermal Disequilibrium at the Top of Volcanic Clouds and its Effect on Estimates of the Column Heights, Nature 355, 13 February, pp. 628 - 630.

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the USGS, the University of Alaska Fairbanks/Geophysical Institute (UAF/GI), and Alaska Division of Geological and Geophysical Surveys (ADGGS). Primary facilities of AVO are at the USGS in Anchorage, at UAFGI in Fairbanks, and at the USGS in Menlo Park, California. Since its formation in 1988 following the eruption of St. Augustine Volcano, AVO has responded to a seismic crisis at Mt. Dutton, to the Redoubt eruptions of 1989-90, and now to the violent multiple eruptions of Mt. Spurr in 1992. Although intensive monitoring is restricted to the Cook Inlet region, AVO intends to extend its reach to active volcanoes of the Alaska Peninsula and Aleutian Islands in the interest of aviation safety.